Use of a Run Timing Model to Provide In-Season Estimates of Sockeye Salmon *(Oncorhynchus nerka)* Returns to Barkley Sound, 1985

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USE OF A RUN TIMING MODEL TO PROVIDE IN-SEASON ESTIMATES OF SOCKEYE SALMON (*Oncorhynchus nerka*) RETURNS TO BARKLEY SOUND, 1985

by

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ABSTRACT

Steer, G. J. and K. D. Hyatt. 1987. Use of a run timing model to provide in-season estimates of sockeye salmon (Oncorhynchus nerka) returns to Barkley Sound, 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1557: 39 p.

Catch and escapement data were used in a return timing model to forecast weekly and total abundance of returns for three stocks of sockeye salmon (Great Central, Henderson, and Sproat lakes) intercepted in the 1985 Area 23 commercial gillnet and seine fishery. Although forecasts from the model were sensitive to return timing assumptions, curtailment of the fishery was correctly advised by the fourth of seven scheduled fishery openings. The achieved exploitation rate of 56% was less than the 77% pre-season forecast and reflected lower than expected returns. Temporary pooling of sockeye between the fishery and escapement enumeration sites, possibly due to high temperatures in the Somass River, biased downward the in-season return forecasts. The model provides a basis for management of the Area 23 net fishery using data on size of catch, catch composition by stock and daily escapements to Great Central and Sproat lakes.

RESUME

Steer, G. J. and K. D. Hyatt. 1987. Use of a run timing model to provide in-season estimates of sockeye salmon (Oncorhynchus nerka) returns to Barkley Sound, 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1557: 39 p.

Les auteurs ont utilisé des données sur les prises et l'échappée pour élaborer un modèle du moment de la remonte servant à prédire l'abondance hebdomadaire et totale des saumons rouges amontants appartenant à trois stocks (lacs Great Central, Henderson et Sproat) exploités commercialement en 1985 au filet maillant et à la senne dans le seacteur 23. Quoique les prévisions obtenues du modèles tenaient compte des hypothèses sur le moment de la remonte, on a obtenu une prévison correcte d'une diminution des ressources pour la quatrième des sept dates d'ouverture de la pêche prévues. Le taux d'exploitation obtenu de 56% était inférieur à la prévision pré-saisonnière de 77% et traduisait des remontes moins importantes que celles attendues. Le groupement temporaire des saumons rouges entre la pêcherie et les sites de dénombrement des saumons amontants, peut-être à cause de températures élevées dans la rivière Somass, a entraîné une déviation à la baisse des prévisions de la remonte pendant la saison. Le modèle fournit une base de gestion de la pêche au filet dans le secteur 23, gestion fondée sur les prises, la composition des prises par stock et les échappées quotidiennes dans les lacs Great Central et Sproat.

INTRODUCTION

Management of the commercial gillnet and seine fishery for sockeye salmon (Oncorhynchus nerka) in Pacific Fishery Management Area 23, Barkley Sound, consists of first setting annual escapement objectives. Then, pre-season and in-season forecasts of stock abundance are used in conjunction with estimates of catch, escapement, number of fishing vessels and catchability to regulate fishery openings in order to achieve those objectives(Fig. 1). Pre-season forecasts of return abundance are calculated from either smolt abundance, marine survival and age at return data (Hyatt and Rome, unpubl. data) or from spawner abundance and returns per spawner data (D. Girodat, DFO, Port Alberni, B.C., pers. comm.). These forecasts and previously observed return timing data are used by fishery managers to plan fishery openings in advance of the season and by the fishing industry to plan vessel deployment and catch processing requirements. Forecasts of adult returns are subsequently recalculated in-season on a weekly basis for each stock from catch, escapement, and return timing data. The weekly forecasts are used during the season along with total catch and catch per unit effort data from the fishery to modify the pre-season fishing plan and account for deviations in abundance of returns from those expected. This study will focus on the provision of in-season abundance forecasts for sockeye that returned in 1985 to spawn in Great Central, Sproat, and Henderson lakes, located on the west coast of Vancouver Island (Fig. 2). Generally, all three stocks are intercepted by a commercial net fishery that operates in Area 23 for 3 to 7 weeks from mid-June through July (Steer et al. 1986; Hyatt and Steer 1987).

Collection and analysis of data on these stocks has been shared between two Branches of the Department of Fisheries and Oceans since 1970 and is currently coordinated by the Barkley Sound Technical Working Group (BSTWG). The Enhancement Assessment Unit (EAU), a joint program of the Fisheries Research Branch (FRB) and the Salmonid Enhancement Program (SEP), monitors the escapements of the three Barkley Sound stocks, the resulting in-lake abundance of juvenile sockeye, and the age and stock composition of the Area 23 catch to evaluate net increases in adult sockeye production due to fertilization of nursery lakes. Great Central Lake has been fertilized each year from 1970 to 1973 and from 1977 to present, Henderson from 1976 to present and Sproat Lake was fertilized for the first time in 1985.

Sockeye escapements to Great Central and Sproat lakes are counted hourly by electronic fish counters (Pulsar Electronics Ltd., Vancouver, B.C.) placed in fishways on the Stamp and Sproat rivers, respectively (Authors, unpubl. data). Hyatt et al. (1985) may be consulted for a brief description of the calibration and use of a Pulsar counter to generate precise estimates of escapement of sockeye to Hobiton Lake, B.C. Sockeye escapement to Henderson Lake is estimated by mark-recapture of adults on the spawning grounds (Authors, unpubl. data). The Field Services Branch (FSB) monitors catch, catch per unit effort, and number of vessels by gear type in Area 23 and is responsible for fishery management. Current management objectives in Area 23 are for sockeye escapements of 200,000 to Great Central Lake, 150,000

to Sproat Lake and 65,000 to Henderson Lake; and for a 60:40 allocation of catch between seine and gillnet fleets (Anon. 1985).

Since 1985, the EAU has provided Area 23 fishery managers with in-season forecasts of return abundance calculated from catch, escapement and return timing data. Prior to this, the fishery was managed on the basis of catch and escapement objectives but there was no formal attempt to reforecast returns during the season. The objectives of the exercise in 1985 were, for each of the three stocks, to forecast annual returns, calculate annual allowable catch in excess of required escapement and given the proposed fishing schedule, predict weekly catch and escapement in future weeks during the season. This information was provided to fishery managers on a regular basis during the fishery for consideration in modifying the Area 23 fishing plan. These forecasts also enabled the EAU to execute its experimental design for catch and escapement biosampling and electronic fish counter calibration.

METHODS

The Area 23 in-season return forecasting model is similar to the in-season models used for managing the salmon fisheries in Nushagak Bay, Alaska, (Hornberger and Mathisen 1982); the sockeye fisheries on the Skeena River (Sprout and Kadowaki 1987); and the sockeye fisheries in Bristol Bay, Alaska (Minard and Meacham 1987). All of these models are versions of an earlier model by Walters and Buckingham (1975). To estimate total abundance of returns, cumulative returns to date are divided by the average cumulative proportion of returns to date, derived from historic return timing data. At the start of the season, pre-season forecasts are used to estimate total returns. Total allowable catch remaining is calculated by subtracting the target escapement and the catch to date from the estimate of total returns. If there is an allowable catch remaining, it is proportionately allocated by the model across the remaining scheduled openings in relation to the expected abundance of returns in each opening. In the event that forecast annual returns are revised upwards, total allowable catch remaining may exceed total returns in the remaining scheduled openings. Since the model only predicts catches for scheduled openings, it assumes that all returns in those openings are harvested and the excess allowable catch is permitted to escape. Under these conditions it is likely that the fishery managers would schedule additional openings. The model may then be run to determine the impact of the revised schedule on predicted catches and escapements.

We use a time step of one week to simplify data requirements. Weekly returns are estimated by multiplying the estimated total returns by the average proportion of returns by week from the historical return timing data. Forecast weekly escapement is either (i) estimated weekly return minus actual catch, if the fishery has occurred or (ii) estimated weekly return minus estimated catch, if a fishery is scheduled. Calculations are conducted for each stock to produce both predicted and observed estimates of weekly catches

and escapements. These estimates are summed across stocks to produce predicted and observed estimates of weekly catches and escapements for all of Area 23.

Return timing curves for Great Central and Sproat sockeye in the fishery were calculated by adding weekly catch to weekly escapement, lagged for a migration delay from the fishery to the electronic fish counters on the Stamp and Sproat rivers, respectively (Fig. 2). Delays were calculated for each stock using sockeye tagging data from Manzer et al. (1985) and were assumed constant both within and between seasons. Their best estimates of migration times were 9d and 7d for sockeye travelling from Pocahontas Point to the counter sites on the Stamp and Sproat rivers, respectively. These journeys can be broken down into a common 32.3 km saltwater leg from Pocahontas Point to the mouth of the Somass River, a 29.4 km freshwater leg to the counter site on the Stamp River, and a 12.1 km freshwater leg to the counter site on the Sproat River. They can be represented by two simultaneous equations:

$$(1)\quad 32.3\text{ km} / x + 29.4\text{ km} / y = 9\text{ d}$$

$$(2)\quad 32.3\text{ km} / x + 12.1\text{ km} / y = 7\text{ d}$$

where x = migration rate (km/d) in saltwater
y = migration rate (km/d) in freshwater

Solving these two equations yields migration rates of 5.7 km/d in saltwater and 8.7 km/d in freshwater. The distance from the upstream boundary of sub-area 23-2, usually the last sub-area within which commercial fishing is permitted, to the mouth of the Somass River is 15.4 km so the estimated migration lags from the fishery to the counters are 6d for Great Central sockeye and 4d for Sproat sockeye. These estimates are supported by the observation that the escapement rates at the Great Central and Sproat counters drop off 6 and 4 days, respectively, after a fishery opening (Authors, unpubl. data).

Fishery weeks in the model run from Monday to Sunday with corresponding sockeye escapements to Sproat from Friday through Thursday (4d lag from fishery to counter) and to Great Central from Sunday through Saturday (6d lag). Week 1 was defined as starting on the Monday with Julian date closest to day 133, which in 1985 corresponded to May 13. Because electronic counter installation and removal dates varied between years, sockeye run timing curves were calculated from week 4, the first week in June, through week 19, the third week in September. This interval normally includes >98% of the annual sockeye returns to Sproat and Great Central lakes (Authors, unpubl. data).

Average cumulative proportions of sockeye returns by week for Great Central and Sproat were calculated from catch and escapement data from 1980, 1981 and 1983 (Authors, unpubl. data). In these years, electronic escapement estimates were available for Great Central and Sproat sockeye and assignment of catch to opening was simplified by the absence of openings that extended over two weeks. Data from 1982 were not included because parasite data which are used to assign catch to stock (Table 1) were not collected.

Average proportion of total returns by week (Fig. 3) was calculated for each stock by subtracting the average cumulative proportion in week t-1 from that in week t.

Forecasts of returns based on run timing models are highly sensitive to assumptions about return timing. To date, we have not conducted an analysis of the contribution of various factors (e.g. run size, ocean temperature, etc.) to interannual variations in return timing. In the absence of this analysis, the sensitivity of results to return timing assumptions used here was indicated by running the model with the average return timing curve shifted forward and backward by one week.

Escapement of Henderson sockeye is not monitored during the season so the model combines the pre-season forecast with a weekly timing curve for the Henderson stock from Starr et al. (1984) to forecast weekly returns.

Data used for both pre-season and in-season forecasts of stock abundance are summarized in Table 1. Data on the age and stock composition of the Area 23 commercial net catch and the abundance and age composition of the escapements to Great Central and Sproat lakes in 1985 were collected by the EAU (Authors, unpubl. data). Weekly catch estimates were from hailed catch and gear counts made by Fisheries Officers on the Area 23 fishing grounds (L. Freeman, DFO, Port Alberni, B.C., pers. comm.). The EAU also monitored returns of sockeye to Hobiton Lake, south of Barkley Sound. This stock returns earlier than the Barkley Sound stocks (Hyatt et al. 1985 and Fig. 3) and is used as an early indicator of return timing and abundance.

RESULTS

An abridged summary of Memoranda containing the arrangements for information exchange among members of the Barkley Sound Technical Working Group and those containing the management advice given by the EAU during 1985 is provided in Appendix I.

In 1985, seven weekly openings of 3d duration for both seine and gillnet fishing were initially scheduled starting with the June 10 opening and ending with the July 22 opening. Each weekly fishery opened at 0800h Monday and closed 0800h Thursday unless curtailed or extended. The returns per spawner method produced a pre-season forecast of 1,800,000 sockeye returning to Area 23 in 1985 (D. Girodat, DFO, Port Alberni, pers. comm.). To initiate the model, we assumed stock contributions of 55% Great Central, 35% Sproat, and 10% Henderson (approximate means of multiyear stock composition, Hyatt and Steer 1987) to produce stock-specific pre-season forecasts of sockeye returns to Great Central of 990,000, to Sproat of 630,000, and to Henderson of 180,000. Escapement targets were 200,000, 150,000, and 65,000, respectively (Anon. 1985).

Management of the first three fisheries, opening June 10, June 17 and June 24, proceeded on the basis of the pre-season forecasts (forecast values listed opposite the June 10th opening in Table 2). Figure 4 shows the predicted weekly returns of sockeye expected from the pre-season return forecasts and the return timing curves, if one assumes the runs had average timing (Average Run Timing - ART). The Great Central and Sproat stocks show similar run timing which is earlier than that for the Henderson stock. The proposed fishing plan would result in heavy exploitation early in the season, primarily harvesting Great Central and Sproat sockeye, and reduced exploitation later in the season, conserving the Henderson run.

An in-season return estimate was available June 17 but was not transmitted to fishery managers because the estimate from the ART scenario was close to the pre-season estimate and it was based on only 2 weeks of data representing less than 2% of the projected returns.

On June 25, the first in-season update to managers was produced on the basis of data acquired by the end of the first two fishery openings (Fig. 5). In addition to the ART scenario, we also calculated forecasts for return timing curves shifted one week early, the early run timing (ERT) scenario, and for the curves shifted one week late, the late run timing (LRT) scenario. Although we did not assign probabilities to these events, the three scenarios provide a measure of the sensitivity of the results to assumptions about return timing. Return estimates for Great Central and Sproat were less than pre-season expectations under both ERT and ART assumptions. The LRT assumption increased forecast returns above pre-season expectations. The ART forecasts were 500,000 to Great Central and 335,000 to Sproat. Forecasts made early in the season are very sensitive to the timing assumption because the cumulative proportion of returns early in the season is comprised of just a few average weekly proportions, and the subtraction or addition of one of these average proportions to simulate early or late timing has a large effect on the cumulative proportion. Even with downward revisions, the allowable catch under both ART and LRT assumptions was large enough to continue fishing. If the runs were early, escapement targets were already compromised. However, supplementary observations (steady returns of sockeye to Hobiton Lake) suggested that Barkley Sound sockeye returns were more likely to be either on time or late, than early.

Forecasts of aggregate returns to the Somass River did not change substantially in the second update, produced on July 3 during the fourth opening. However, we halved the return forecast for Henderson to reflect the in-season revisions of Somass returns under the ART scenario. This scenario resulted in more conservative predictions than the LRT scenario and seemed more likely since sockeye returns to Hobiton Lake still did not appear to be late (Authors, unpubl. data). Although estimates of allowable catch remaining were still large under the ART assumption, we recommended a fishery of 1d duration for both gear types in the fifth opening with further fishing contingent on improvements in escapement since escapements to Great Central and Sproat were only 24,000 (12% of target) and 23,000 (15% of target), respectively. Fishery managers reduced the length of the opening from the 3 days scheduled for fishing by both gear types to 2d for gillnet and 1d for seine fishing.

In the third update, produced July 9, in-season return forecasts under the ART assumption were similar to those of the previous week but forecasts in the ERT and LRT scenarios increased and decreased, respectively (Fig. 6). If the runs were on time, the total allowable catch remaining was 250,000. However, catches declined to less than one-half of those in the previous week. We used catch data from the fourth opening and an exploitation rate of 80%, the average for the first three openings, to calculate estimates of weekly returns of Somass stocks in the fifth opening. These were less than predicted under the ART assumption and it appeared that the Somass stocks had peaked early. We recommended cancellation of the sixth opening to build escapement, which was still less than 20% of the Somass objective. We also made two predictions for escapements from the fifth opening. First, if the runs were early, as suggested by the results from the fishery in the fifth opening, escapements of 16,000 and 12,000 would appear at the Great Central and Sproat counting sites in the following week. Second, if they were on time, the respective escapements would be 46,000 and 31,000. Even if the fishery was closed during the sixth scheduled opening and the latter timing hypothesis proved correct, the allowable catch in excess of escapement could still be taken in the remaining openings.

In response to a request by fishery managers for an updated return forecast, the model was run on July 12 using actual Sproat returns and estimates of Great Central returns from the fourth opening. Because of the different migration lags, the Sproat escapement from this opening was complete but that to Great Central was only partially counted so 4d of Great Central escapement were averaged and then multiplied by 7. Return forecasts under the ART assumption dropped further resulting in a combined allowable catch of only 95,000. At this point, the in-season forecast was less than the pre-season forecast even if the stocks were late by one week. This supported our recommendation of closure for the sixth opening. Fishery managers closed the Area 23 net fishery until further notice.

The fourth regular update, on July 17, used actual return data from the fourth opening for both Somass stocks; return forecasts did not change from those of the special update on July 12. Weekly returns in the fourth opening dropped from an apparent peak in the third opening. Those in the fifth, as estimated from the catch, dropped further, indicating that the Somass runs may have peaked early, i.e. the actual pattern of returns to date more closely matched the ERT forecast distribution than either the ART or LRT distributions (Fig. 7). We hypothesised that part of this drop might be due to high temperature in the Somass River forcing sockeye to hold in sub-area 23-1, an area closed to fishing. Water temperatures in excess of 19°C have been found to delay sockeye entry into the Okanagan River from the Columbia River (Major and Mighell 1967). On July 12, water temperature had climbed to 20.5°C in the Stamp River and in the Sproat River was 22.0°C. Water temperatures of 25°C are lethal to sockeye (Brett 1952). Hydroacoustic assessments of this sub-area suggested a two fold increase in fish abundance over the previous week (T. Mulligan, DFO, Nanaimo, B.C., pers. comm.). Although there was a theoretical catch of 95,000 remaining if the stocks were on time, we recommended continued closure of the fishery for conservation reasons as Somass escapement was still 290,000 short of target and considerable uncertainty existed as to how many sockeye were actually holding in sub-area 23-1.

The fishery remained closed for the rest of the season. Weekly escapement (Fig. 8) continued to drop off until the beginning of August when migration through the counters increased (Fig. 9), coincident with rainfall from August 3 through 9 (AES 1986) and lower temperatures in the Somass River. This rainfall event was the first since July 4. Water temperature in the Somass River above tidal influence dropped from 21°C on July 25 and 29 to 19°C on August 1, 6, and 12. The escapement target of 150,000 sockeye to Sproat Lake was met by a total escapement of 146,951 (Authors, unpubl. data). Escapement to Great Central Lake was 120,274 (Authors, unpubl. data), only 60% of the 200,000 sockeye objective, and that to Henderson Lake was 23,000 (P. Rankin, DFO, Nanaimo, B.C. pers. comm.), only 35% of the 65,000 objective. The Area 23 commercial net fishery took 208,480 Great Central, 159,437 Sproat, and 7,403 Henderson sockeye for a total catch of 375,320 (Authors, unpubl. data). The overall exploitation rate of the three sockeye stocks was 56%.

DISCUSSION

The exploitation rate of 56% achieved by the commercial net fishery was a considerable reduction from the 77% rate proposed in advance of the season and reflected the lower than expected abundance of returns detected by the in-season forecasting model. If the returns had been harvested at the rate proposed pre-season, aggregate escapement to the Somass system would have been 145,000, i.e. less than half of the escapment objective rather than the 290,000 achieved. In 1984, Barkley Sound sockeye stock returns of 1,180,000 were harvested at 78% to leave 265,000 for escapement (Authors, unpubl. data). Thus, it appears that provision of in-season return forecasts to Area 23 fishery managers in 1985 improved their ability to meet escapement objectives in the face of variations in return rates.

The reliability of our in-season return forecasts deteriorated late in the season apparently due to a specific problem in 1985 of fish holding between the fishery and the escapement counting sites, probably in sub-area 23-1 at the mouth of the Somass River. The present model assumes that the migration rates in saltwater of 5.7 km/d and in freshwater of 8.7 km/d are constant throughout the season. These rates are within the range reported for tagged fish from other sockeye stocks (Table 2). Schaefer (1951) reported that tagged sockeye took 16.7 and 18.3 d to travel 63 km from Skookumchuck on the Lillooet River to a fish trap on the Birkenhead River in 1940 and 1941 (3.7 and 3.4 km/d). Smith and Jordan (1973) reported that tagged sockeye took 27 d to migrate 378 km from the test fishing site at the mouth of the Skeena River to the Babine fence fish counting facility (14 km/d). Major and Mighell (1967) estimated that 7 to 9 d were required for sockeye to migrate 246 km from the Rock Island dam on the Columbia River to the Zosel Dam on the Okanagan River (27 to 35 km/d). The migration rate of Somass sockeye appeared to decrease coincident with water temperatures in excess of approximately 20°C and increase again with the passage of a major weather front, the onset of rain and lower water temperatures in the Somass River. Major and Mighell (1967) concluded that water temperatures $\geq$ 19°C in the Okanagan River delayed

entry of sockeye from the Columbia River. Although migration of Sproat sockeye increased coincident with the rainfall event in early August and continued throughout that month, water temperatures in the Sproat River remained above 19°C until September 9. The relationship between water temperature and migration rate of sockeye in the Somass system is therefore inconclusive. However, the influence of passage of a weather front on increasing migration rate is consistent with observations by Ellis (1962) on factors affecting migration rate of Somass sockeye.

The assumption of constant migration rate is violated by pooling of sockeye between the fishery and the fish counters which causes the model to underestimate total abundance of returns in some weeks associated with high water temperatures. If direct measures of the pool size (e.g. hydroacoustic assessments) are unavailable, a more reliable estimate of total returns late in the season may be obtained by replacing these weekly returns with estimates based on catch and the exploitation rates from earlier openings as we did for predictions associated with openings four and five.

A more general problem in all years for use of the present model is based on the fact that the commercial fishery operates in subareas 23-2 to 23-10 in the outside waters of Barkley Sound and Alberni Inlet prior to the enumeration of sockeye escapements through electronic counters at the Sproat Falls and Great Central Lake fishways (Fig. 2). Consequently, weekly returns of sockeye associated with a given fishery opening are not known until at least a week after the end of the opening. A one-week delay in weekly return assessments forces fisheries managers to make decisions about the advisability of an upcoming opening without the benefit of a total return estimate from the opening most recently completed. This in turn increases the uncertainty of making a decision that will optimize the trade-off between catch and escapement objectives for Barkley Sound sockeye. In some fisheries weekly returns are estimated on the basis of historical relationships developed between catch per unit effort (CPUE) data and independent estimates of total returns. CPUE data are obtained either from the commercial fishery (Brannian 1982) or from a standardized test fishery (Sprout and Kadowaki 1987; Minard and Meacham 1987), thus reducing or eliminating the delay between management decisions and receipt of information about the in-season status of total returns. However, use of commercial CPUE data may not improve forecasts of total returns (Henderson et al. 1987) and a test fishery cannot be used to estimate returns until the relationship between abundance of returns and test fishery CPUE is quantified.

Sensitivity of results to timing assumptions is critical but is presently crudely represented by calculating abundance estimates from timing curves shifted early and late by one week. Future versions of the model will incorporate more years of timing data and calculate statistical prediction intervals. Development of an understanding of the basis for interannual variations in return-timing of Barkley Sound sockeye would clearly improve the utility of the present model for stock management. Consequently, future analyses will include a search for predictive relationships between interannual variations in sockeye return-timing and variations in factors such as ocean climate (as indexed by temperature) or returns of other stocks (e.g. Hobiton sockeye). Currently, estimates from the three run timing scenarios are useful for identifying what timing must be assumed to achieve total returns of a certain magnitude given returns to date.

Estimates of total returns produced by the model were assumed to be unreliable early in the season so pre-season forecasts were implicitly used. Henderson et al. (1987) have shown for sockeye returning to Smith Inlet that pre-season forecasts based upon escapement, return per spawner, and age at return data are better predictors of return abundance up to the time corresponding to 50% of returns than in-season models using cumulative return timing curves. A weighting curve, using the variances of the predictors at time, should be used to objectively and explicitly combine pre-season and in-season return estimates (Walters and Buckingham 1975).

Given the magnitude of the exploitation rate required to achieve escapement objectives, small deviations in catch resulting from imperfect information lead to large deviations in escapement. For example, if the Area 23 stocks return at 1,500,000, they must be exploited at 72% to achieve target escapements. A 10% error in catch, which can correspond to only one day's fishing in the latter half of the season given recent effort levels, produces a 26% error in escapement, or 110,000 out of 415,000. Assuming a return per spawner ratio of 4:1, this corresponds to a foregone future harvest of 330,000 sockeye.

Fortunately, the Area 23 stocks return over a rather extended time period, with 70% of the Sproat stock returning over 4 weeks, 60% of the Great Central stock returning over 4 weeks and 53% of the Henderson stock returning over 2 weeks near the end of fishing season. By contrast, 65% of the Bristol Bay sockeye run passes through the fishery in 2 weeks (Minard and Meacham 1987). The prolonged nature of the Area 23 fishery combined with in-season feedback of information on projected total returns permits adjustment of exploitation rates in the later openings to achieve escapement goals.

In addition to providing a basis for making fishery management decisions, the model identifies the critical information required for management and provides a framework for its use. The first component, catch, consists of abundance of catch and stock composition data by opening, the latter necessary due to the mixed stock nature of the fishery and the stock specific escapement objectives. The second component, escapement, consists of daily escapement counts by stock which are then lagged to estimate weekly escapement by stock from the fishery. Age composition data are presently not used in the model but would be required to model return timing by stock and age. Even in its present unsophisticated form, the Area 23 return forecasting model is a useful adjunct to management of the Barkley Sound sockeye stocks.

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Table 1. Types, uses and sources of data employed in various aspects of management of the commercial net fishery for sockeye in Area 23.

Data Type	Use	Sources and Methods of Acquisition
Smolt abundance, size and age by stock.	Pre-season forecasts of annual returns by stock.	FRB/SEP - hydroacoustic, trawl, and smolt surveys (Hyatt et al. 1984; Hyatt and Stockner 1985; Hyatt and Rome, unpublished data).
Mean ocean age at return by stock.	Pre-season forecasts of annual returns by stock.	FRB/SEP - catch and escapement sampling (Manzer 1976, Steer et al. 1986).
Mean return time by stock.	Pre-season forecasts of weekly returns by stock and in-season forecasts.	FRB/SEP - weekly escapement assessments to Great Central and Sproat 1981-1984.
Weekly escapements to Great Central and Sproat lakes.	Weekly revisions of in-season forecasts by stock.	As above
Weekly estimates of Barkley Sound sockeye catch.	Weekly revisions of in-season forecasts by stock.	FSB hailed catch estimates.
Stock composition of catch by commercial opening and gear.	Weekly revisions of in-season forecasts by stock.	FRB/SEP - catch sampling and processing stock-specific parasite "tags" (Steer et al. 1986; Quinn et al., 1987).
Age composition of catch by commercial opening and gear.	Post-season assignment of production to brood year.	FRB/SEP and FSB (unpublished data).
Estimates of Hobiton sockeye weekly catch and escapement.	Early indicator of whether return timing of Barkley Sound sockeye is early, late or average.	FRB/SEP - assessments of weekly catch and daily escapements at Hobiton River (Manzer et al. 1984, Hyatt et al. 1985, and Authors' unpublished data).

Table 2. Summary of net catches, escapements and return forecasts of Great Central (GCL), Sproat (Spr) and Henderson (Hen) sockeye in 1985. Opening is date corresponding to Monday of a fishery week. Catch is combined gillnet and seine catches allocated to stock using parasite infection rates. Zero catch denotes scheduled fisheries that were not opened. Advice date is date forecast information transmitted by telephone to fishery managers (See Appendix I for copies of bulletins provided during the 1985 season). Cumulative Somass escapements are as of date indicated and are not adjusted for species composition or counter bias. Forecast returns and allowable catch to come are rounded to nearest 5,000.

	← Com Fishery →			Cumul	Forecast					
					Early		Average		Late	
Opening	Stock	Net Catch	Advice Date	Stock	Somass Escape	Returns	Catch to Come	Returns	Catch to Come	Returns	Catch to Come
June 10	GCL	8,150a	Pre-	GCL	3,086			990,000	790,000		
	Spr	8,150a	season	Spr	4,036			630,000	480,000		
	Hen	0	(Esc to	Hen	-			180,000	115,000		
	Total	16,300	June 9)	Total	7,122			1,800,000	1,385,000		
June 17	GCL	35,134a	June 17b	GCL	8,781	220,000	15,000	1,040,000	830,000	990,000	780,000
	Spr	35,134a	(Esc to	Spr	8,733	145,000	0	420,000	260,000	1,290,000	1,135,000
	Hen	0	June 16)	Hen	-	180,000	115,000	180,000	115,000	180,000	115,000
	Total	70,268		Total	17,514	545,000	130,000	1,640,000	1,205,000	2,460,000	2,030,000
June 24	GCL	76,585	June 25	GCL	12,544	165,000	0	500,000	255,000	2,440,000	2,195,000
	Spr	51,056	(Esc to	Spr	13,634	130,000	0	335,000	140,000	875,000	680,000
	Hen	0	June 23)	Hen	-	180,000	115,000	180,000	115,000	180,000	115,000
	Total	127,641		Total	26,178	475,000	115,000	1,015,000	510,000	3,495,000	2,990,000
July 1	GCL	62,267	July 3	GCL	21,644	235,000	0	510,000	190,000	1,620,000	1,300,000
	Spr	46,417	(Esc to	Spr	23,688	215,000	0	425,000	180,000	1,070,000	825,000
	Hen	4,529	June 30)	Hen	-	90,000	25,000	90,000	25,000	90,000	25,000
	Total	113,213		Total	45,332	540,000	25,000	1,025,000	395,000	2,780,000	2,150,000

Table 2 (cont'd)

Opening	Com Fishery Stock	Net Catch	Advice Date	Stock	Cumul Somass Escape	Forecast Early Returns	Early Catch to Come	Average Returns	Average Catch to Come	Late Returns	Late Catch to Come
July 8	GCL	26,344	July 9	GCL	27,928	315,000	0	540,000	155,000	1,185,000	805,000
	Spr	18,680	(Esc to	Spr	28,128	255,000	0	410,000	120,000	810,000	520,000
	Hen	2,874	July 8)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
	Total	47,898		Total	56,056	660,000	20,000	1,040,000	295,000	2,085,000	1,345,000
			July 12	GCL	28,896	315,000	0	445,000	35,000	755,000	350,000
			(Esc to	Spr	28,416	245,000	0	350,000	40,000	565,000	255,000
			July 11)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
				Total	57,312	650,000	20,000	885,000	95,000	1,410,000	625,000
July 15	GCL	0	July 17	GCL	28,946	310,000	0	445,000	35,000	755,000	345,000
	Spr	0	(Esc to	Spr	28,545	245,000	0	350,000	40,000	565,000	255,000
	Hen	0	July 13)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
	Total	0		Total	57,941	645,000	20,000	885,000	95,000	1,410,000	620,000
July 22	GCL	0	July 23	GCL	29,344	280,000	0	350,000	0	490,000	70,000
	Spr	0	(Esc to	Spr	29,021	220,000	0	275,000	0	385,000	50,000
	Hen	0	July 22)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
	Total	0		Total	58,365	590,000	20,000	715,000	20,000	965,000	140,000
July 29			July 30	GCL	30,850	265,000	0	275,000	0	340,000	0
			(Esc to	Spr	33,860	205,000	0	220,000	0	270,000	0
			July 28)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
				Total	64,710	560,000	20,000	585,000	20,000	700,000	20,000

Table 2 (cont'd)

Opening	+- Com Fishery + Stock	Net Catch	Advice Date	Stock	Cumul Somass Escape	Forecast +------ Early --- --+ Returns	Catch to Come	+----- Average ----+ Returns	Catch to Come	+------ Late ------+ Returns	Catch to Come
Aug 5			Aug 9	GCL	40,177	260,000	0	265,000	0	275,000	0
			(Esc to	Spr	57,372	210,000	0	210,000	0	225,000	0
			Aug 6)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
				Total	97,549	560,000	20,000	565,000	20,000	590,000	20,000
Aug 12			Aug 13	GCL	68,954	295,000	0	290,000	0	290,000	0
			(Esc to	Spr	89,952	245,000	0	245,000	0	250,000	0
			Aug 12)	Hen	-	90,000	20,000	90,000	20,000	90,000	20,000
				Total	158,906	630,000	20,000	625,000	20,000	630,000	20,000

Season Totals[c]	Catch		Escapement
GCL	208,480	GCL	120,274
Spr	159,437	Spr	146,951
Hen	7,403	Hen	23,000
Total	375,320		290,225

Notes [a]Parasite data not available so catch equally allocated to GCL and Spr.

[b]Calculated but not transmitted to fishery managers.

[c]Preliminary

Table 3. Summary of reported sockeye migration rates in freshwater and saltwater.

Location and type	Migration Rate (km/d)	Source
Barkley Sound - marine	5.7	Manzer et al. 1985
Somass River system	8.7	" " "
Lillooet and Birkenhead Rivers	3.4 - 3.7	Schaefer 1951
Skeena River	14.0	Smith and Jordan 1973
Columbia River	27 - 35	Major and Mighell 1967

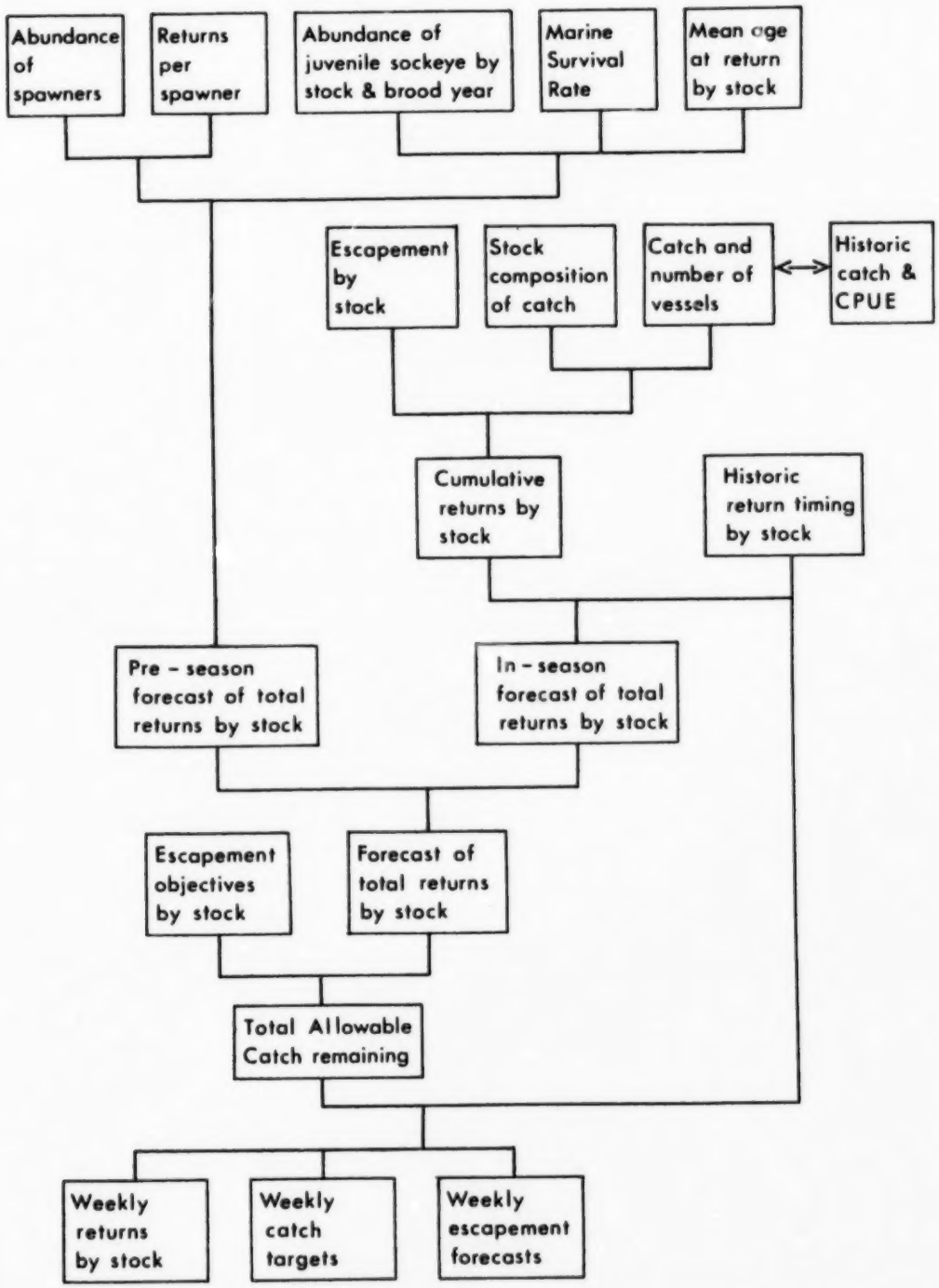

Abundance of spawners
Returns per spawner
Abundance of juvenile sockeye by stock & brood year
Marine Survival Rate
Mean age at return by stock
Escapement by stock
Stock composition of catch
Catch and number of vessels
Historic catch & CPUE
Cumulative returns by stock
Historic return timing by stock
Pre - season forecast of total returns by stock
In - season forecast of total returns by stock
Escapement objectives by stock
Forecast of total returns by stock
Total Allowable Catch remaining
Weekly returns by stock
Weekly catch targets
Weekly escapement forecasts

Fig. 1. Flow chart of information basis for management of the commercial net fishery for sockeye in Pacific Fishery Management Area 23.

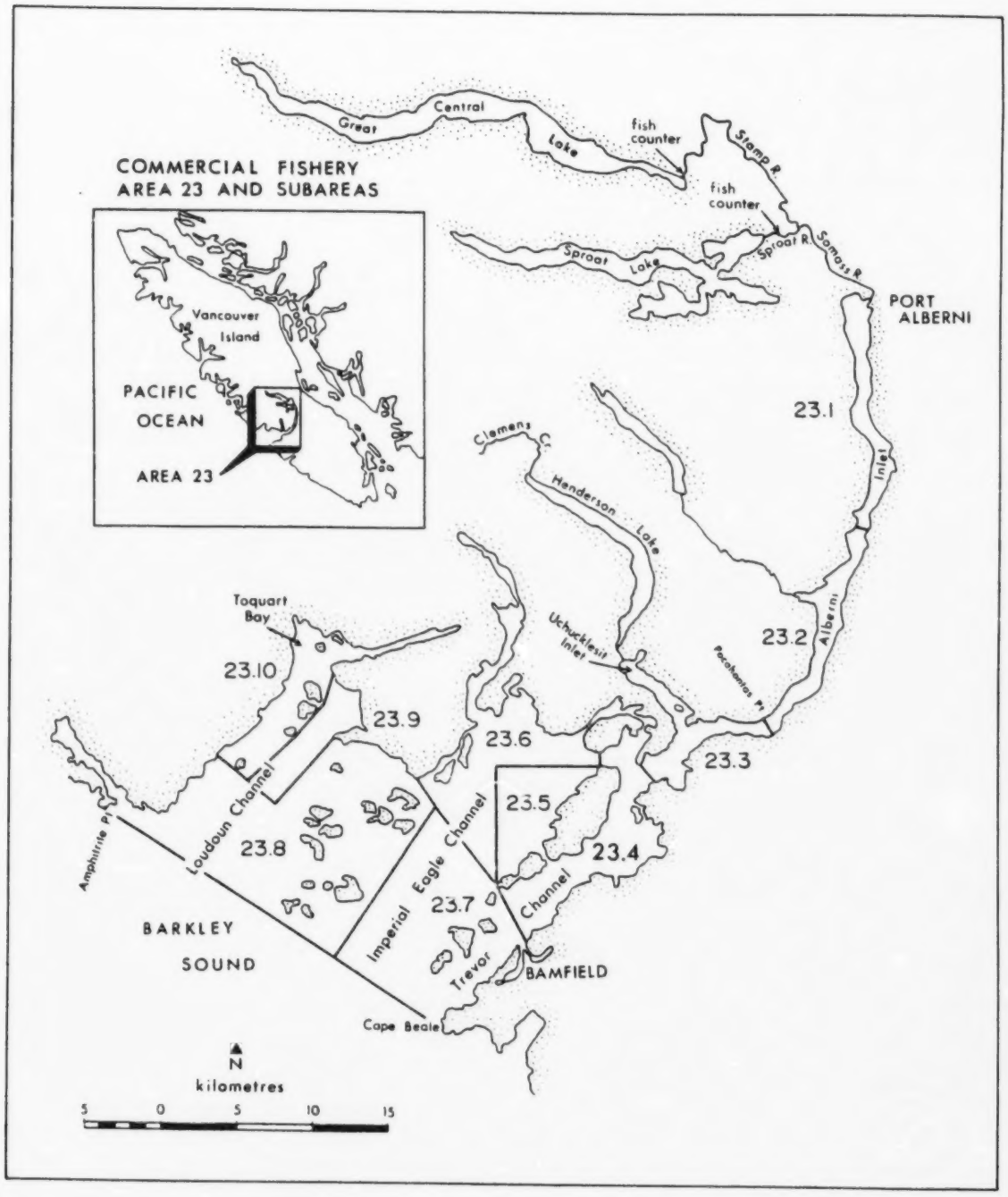


Fig. 2. Pacific Fishery Management Area 23, Barkley Sound, and Great Central, Sproat and Henderson lakes.

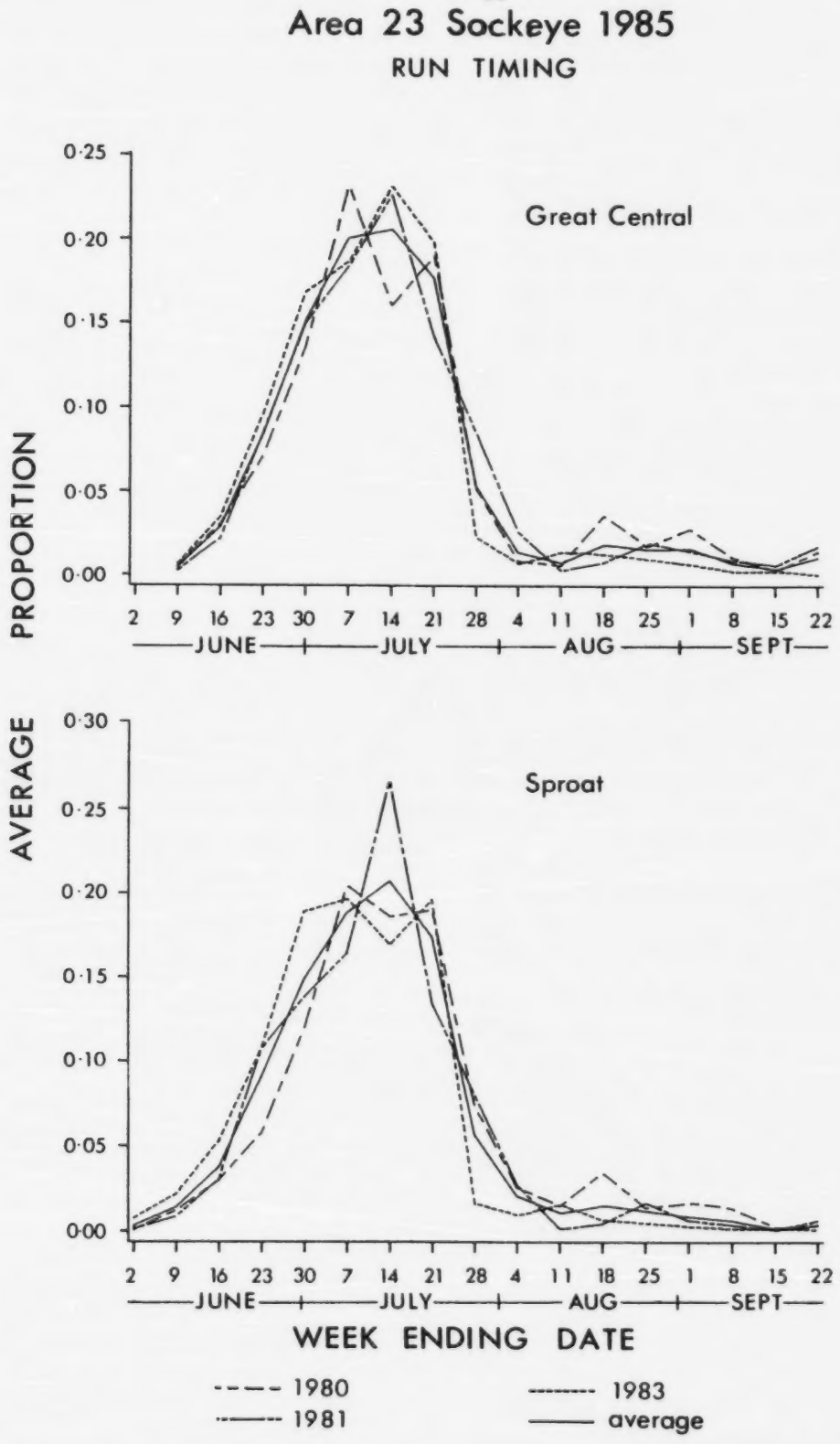


Fig. 3. Return timing curves from weekly catch and lagged escapement estimates (Authors, unpublished data) for Great Central and Sproat sockeye, 1980, 1981 and 1983. Average curve is calculated from means of cumulative returns at time.

Fig. 4. Predicted weekly abundance in Area 23 of sockeye returning to Great Central (GCL), Sproat (Spr) and Henderson (Hen) lakes in 1985. Weekly return predictions are based on average timing curves and pre-season forecasts. Openings are from proposed fishing plan with total allowable catch proportionately allocated across openings. Escapement is predicted return less predicted weekly catch. Week is week ending date in the fishery.

Area 23 Sockeye 1985
PRE - SEASON

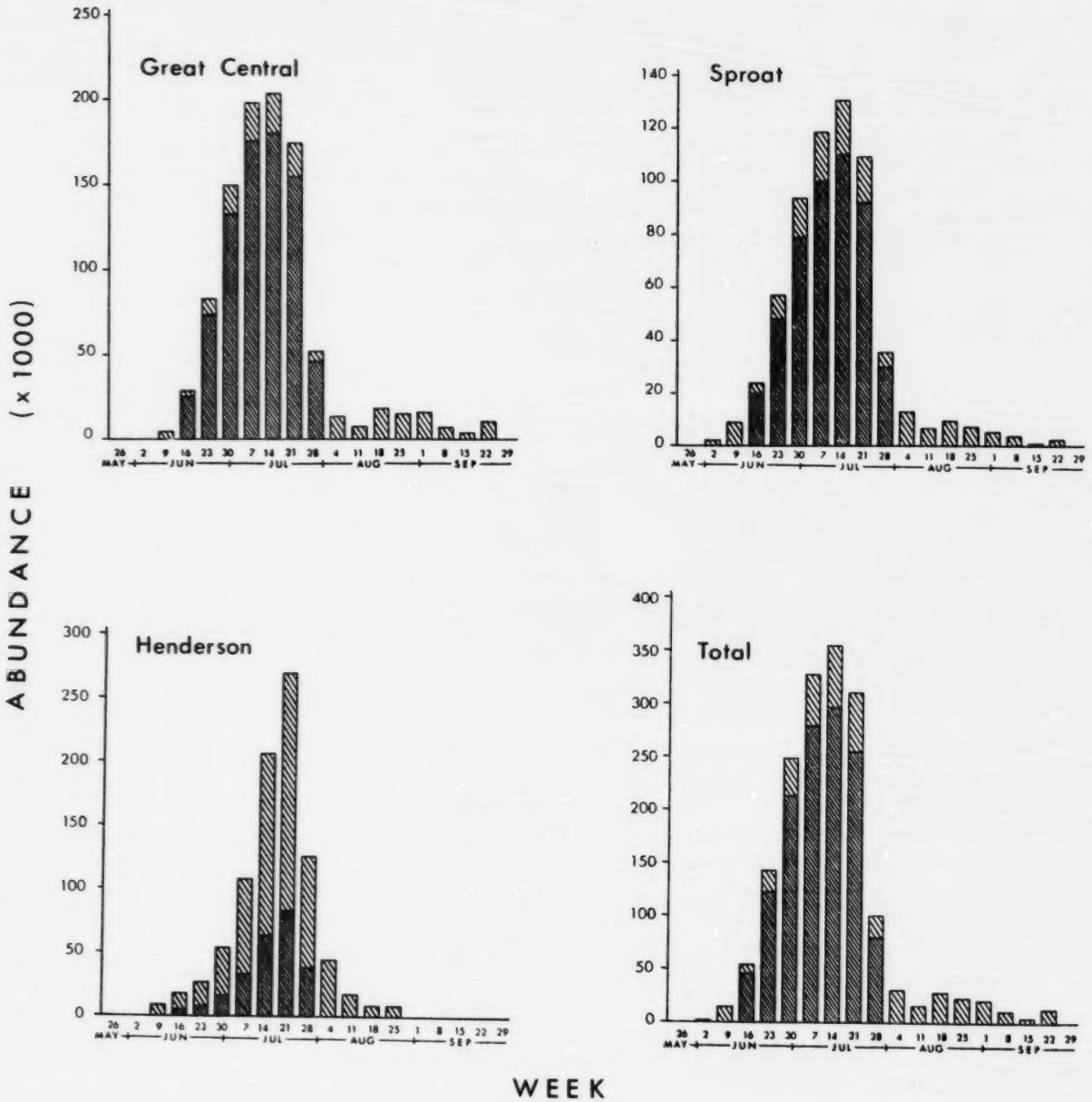


Fig. 5. Actual and predicted weekly abundance in Area 23 of sockeye returning to Great Central (GCL), Sproat (Spr) and Henderson (Hen) lakes in 1985 under early, on-time and late timing scenarios as of 25 June 1985. Week is week ending date in the fishery.

Area 23 Sockeye 1985
JUNE 25

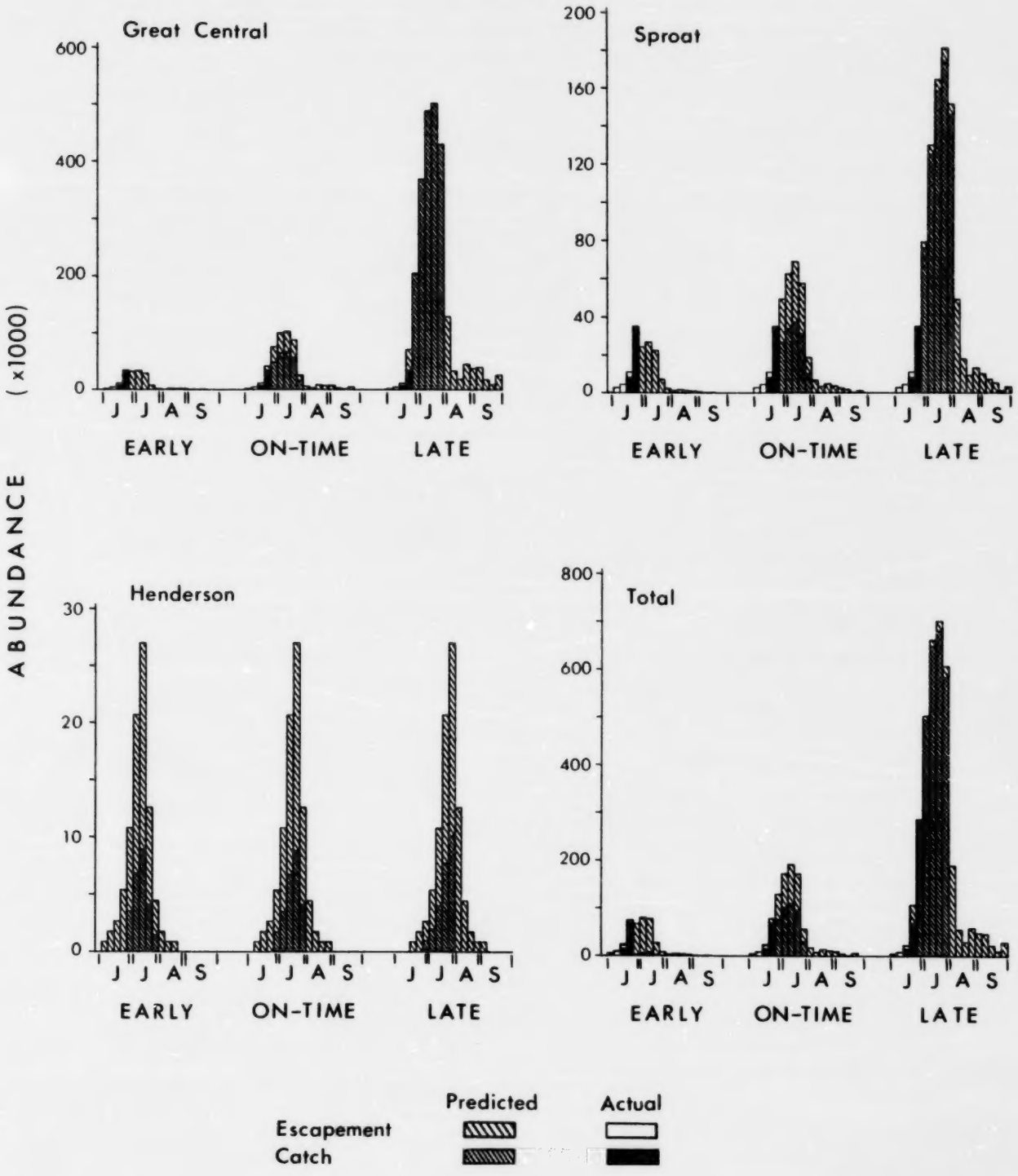


Fig. 6. Actual and predicted weekly abundance in Area 23 of sockeye returning to Great Central (GCL), Sproat (Spr) and Henderson (Hen) lakes in 1985 under early, on-time and late timing scenarios as of 9 July 1985. Week is week ending date in the fishery.

Area 23 Sockeye 1985

JULY 9

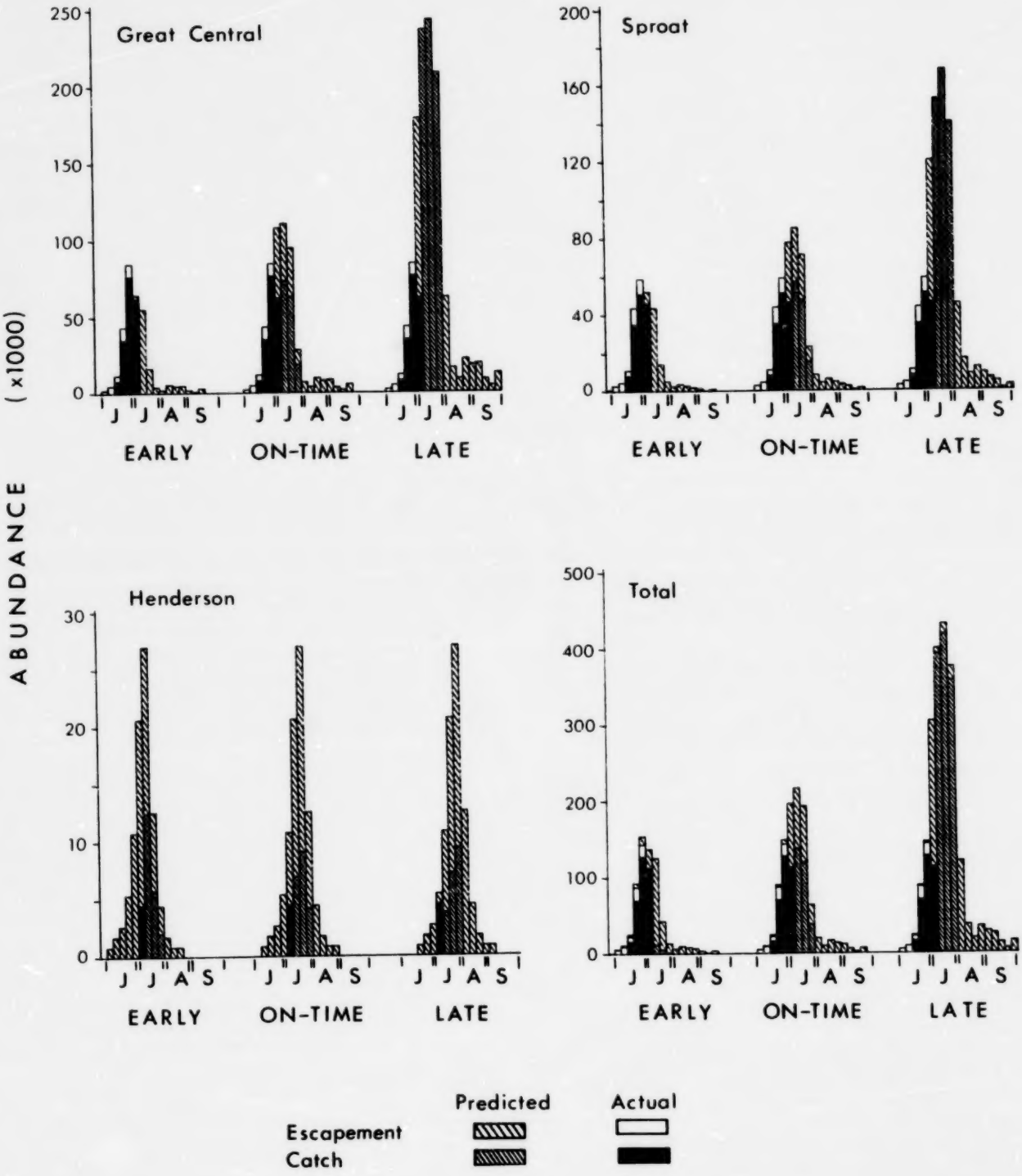


Fig. 7. Actual and predicted weekly abundance in Area 23 of sockeye returning to Great Central (GCL), Sproat (Spr) and Henderson (Hen) lakes in 1985 under early, on-time and late timing scenarios as of 17 July 1985. Week is week ending date in the fishery.

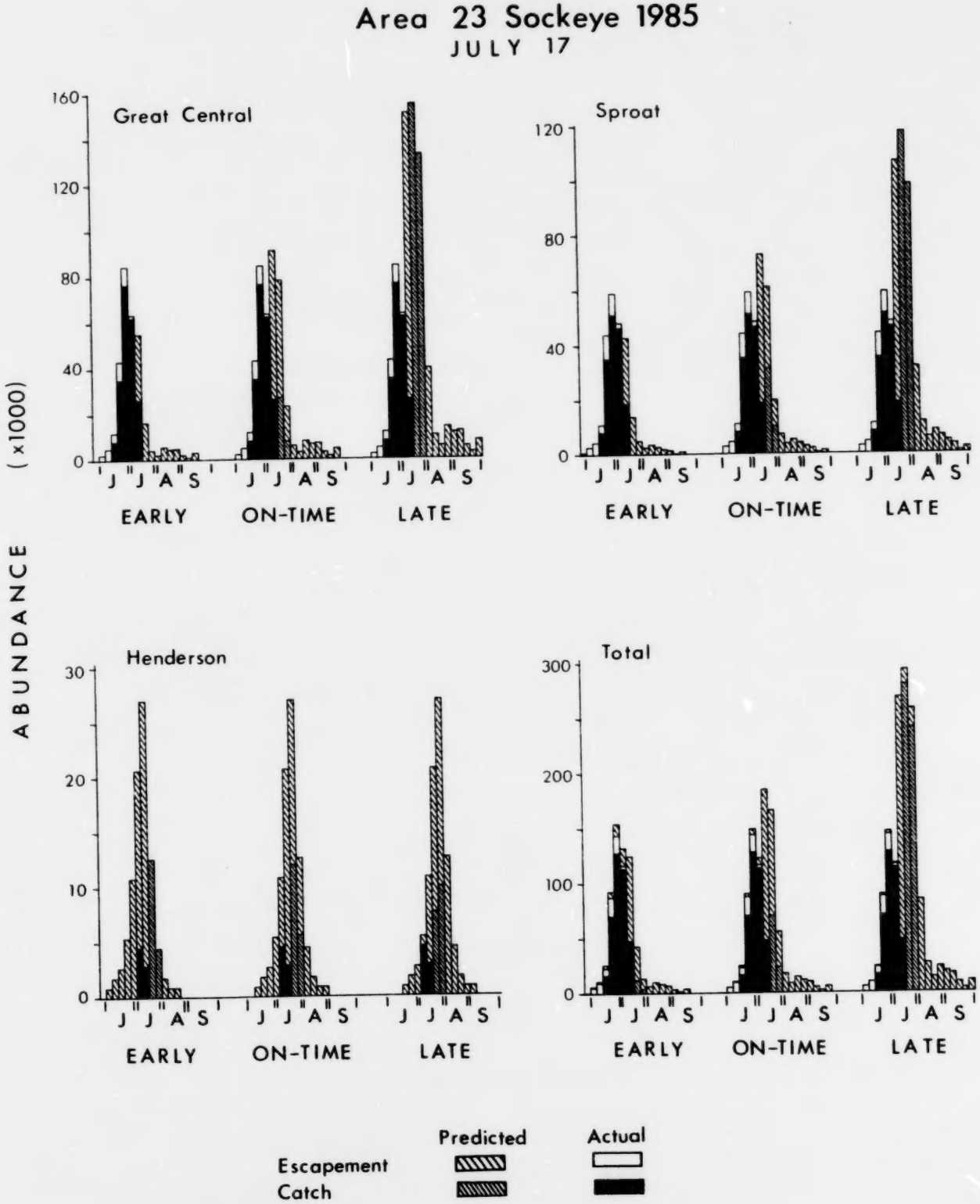

Area 23 Sockeye 1985
JULY 17
Great Central
Sproat
Henderson
Total
ABUNDANCE
(x1000)
EARLY
ON-TIME
LATE
J J A S
Predicted
Actual
Escapement
Catch

Fig. 8. Actual weekly abundance in Area 23 of sockeye returning to Great Central (GCL) and Sproat (Spr) lakes and predicted weekly abundance of sockeye returning to Henderson (Hen) Lake in 1985. Weekly abundance of Henderson sockeye is calculated from average run timing curve and total catch and escapement. Week is week ending date in the fishery.

Area 23 Sockeye 1985
POST-SEASON

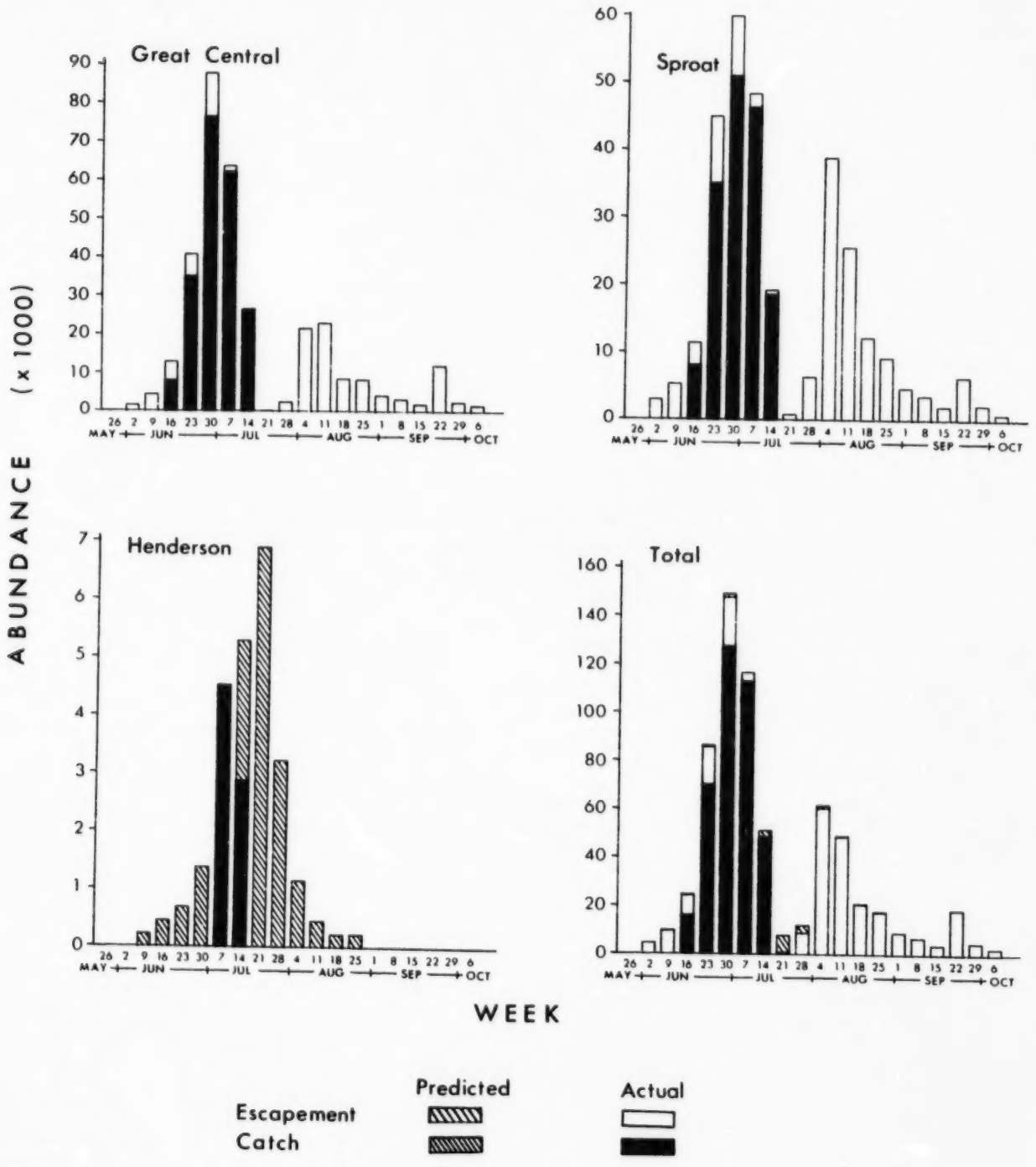
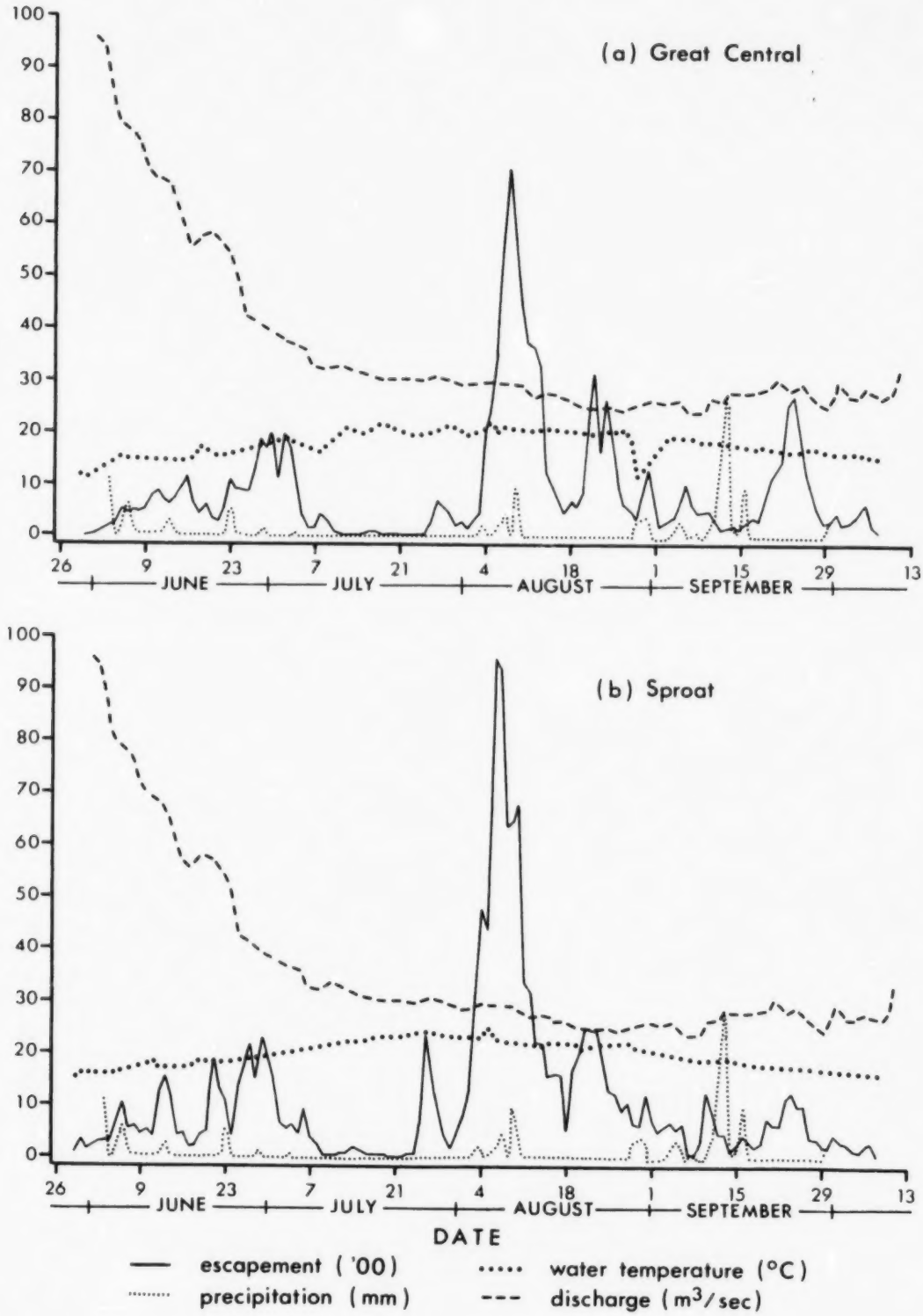


Fig. 9. Daily discharge (m^3/sec) of the Somass River, precipitation at Port Alberni (mm), water temperature (C) of the Stamp River and sockeye escapement to Great Central Lake (a) and water temperature of the Sproat River and sockeye escapement to Sproat Lake (b).


(a) Great Central
(b) Sproat
100
90
80
70
60
50
40
30
20
10
0
26
9
23
7
21
4
18
1
15
29
13
JUNE
JULY
AUGUST
SEPTEMBER
DATE
escapement ('00)
precipitation (mm)
water temperature (°C)
discharge (m³/sec)

Appendix I. Abridged summary of advice provided to Area 23 managers and biologists by EAU personnel in periodic bulletins concerning return strength and options available for management of Barkley Sound sockeye during 1985. Advice date was the date forecast information was transmitted in meetings or by telephone to fishery managers. Actions taken constitute decisions by Area 23 managers and reflect, in part, advice transmitted by EAU personnel. Complete records of in-season bulletins and advice transmitted may be found in Appendix I of PSARC Working Paper 586-2 which may be obtained from the Chairman of PSARC, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C. V9R 5K6.

Advice Date	Advice transmitted	Actions taken
Fall, 1984.	Pre-season forecasts of sockeye return by stock provided to Area 23 managers. Forecasts based on smolt outputs by stock and multiyear marine survival average for Barkley Sound sockeye.	1985 fishing plan formulated to include 3-day openings each week for 7 weeks beginning the week of June 10, 1985.
May 15, 1985.	Pre-season forecasts and fishing plan reviewed by BSTWG.	Fishing plan for 1985 supported by BSTWG. June 10-12, 17-19 and 24-26 openings proceed as scheduled.
June 24-25, 1985.	Arrangements recommended for FRB-FSB consultation during the 1985 sockeye season. Description provided to Area 23 managers/biologists of EAU modelling exercise, model form and output to expect during fishing season.	
	Model calculations indicate 44% reduction for in-season return forecast relative to pre-season forecast. However, fish surplus to escapement should still be available for catch	July 1-3 fishery opening proceeds as scheduled.
July 2-3, 1985.	In-season forecasts are still approximately 40-50% lower than pre-season forecast. Exploitation rates on both Great Central and Sproat sockeye were approximately 80% during the first two fishery openings. As of June 29 only 10% and 20% of desired escapements had been achieved to Great Central and Sproat respectively.	

Advice Date	Advice transmitted	Action(s) taken
	Catch continues to run ahead of escapement and consideration should be given to reducing the length of subsequent openings to reduce the risk of failing to achieve escapement objectives. One day opening recommended for week of July 8th with additional openings contingent on achieving a more satisfactory proportion of targetted escapements to Great Central and Sproat Lake.	Fishery managers reduce July 8 opening length from 3 days scheduled to 2 days for gillnet and 1 day for seine fishing.
July 9-12	An exploitation rate of greater than 80% has been achieved during the first four openings. Only 13.5% of the aggregate escapement target has been achieved to date. Considerable uncertainty exists regarding returns yet to come and it is advisable that the fishery close subject to substantial improvements in escapements.	Area 23 net fishery closed until further notice.
July 17	Cumulative escapements to Great Central and Sproat Lakes had achieved only 14% and 19% of annual target as of July 13. Area 23 fishery should remain closed to build escapements.	Area 23 fishery remained closed.
July 23	High water temperatures in the Somass River and the probability of "holding" by sockeye in Subarea 23-1 precludes the use of average timing curves for return and escapement predictions at this time because calculations in the model assume a constant migration delay from the fishery to the fish counters. Given the uncertainty over returns yet to come and the achievement of only 17% of the overall escapement target as of July 22, the fishery should remain closed.	Area 23 fishery remained closed.

Advice date	Advice transmitted	Action taken
July 30	Weekly returns of both stocks in the week ending July 21 declined precipitously from those of the previous week and from the peak returns in the week ending June 30. The two return timing hypotheses previously identified, the runs are early or the fish are holding, remain untested but we believe that the latter hypothesis, the fish are holding due to high river temperatures, is more likely. This is supported by reports of sockeye concentrations in subareas 23-1 and 23-2 and would bias downward return forecasts made by the model. The recommended management action for this week is to remain closed for the same reasons as last week. If the runs are early there is no allowable catch and we will be fortunate to achieve 70% of the annual escapement objective. If the runs are on time and the fish are holding, the allowable catch is 95,000 and escapement objectives will be met, using return forecasts made for the week ending July 7. However, the high concentration of sockeye at the head of Alberni Inlet, implied by this assumption, would make controlling the fishery difficult. Also escapements were only 19% of the annual target as of July 28. Therefore, we suggest that the fishery remain closed.	Area 23 fishery remained closed
Aug. 9	Weekly returns of both stocks in the week ending July 28 increased over those of the previous week. Escapements have improved substantially, apparently triggered by rain. These improvements tend to support the fish holding hypothesis so return estimates based on timing curves will be low. However, escapements as of midnight Aug. 6 were 40,177 to Great Central	

Advice date	Advice transmitted	Action(s) taken
	and 57,372 to Sproat. These are only 20% and 38% of their respective escapement targets so the recommended management action for this week is for the sockeye net fishery to remain closed.	Area 23 fishery remained closed.
Aug. 13	Weekly returns of both stocks in the week ending August 4 increased substantially over the previous week. Escapements are still strong to both systems. However, cumulative escapements are only 34% and 60% of their respective targets to Great Central and Sproat Lakes. Accordingly, the recommended management action for this week is for the sockeye net fishery to remain closed.	Area 23 fishery remained closed.